

# **DESIGN OF POROUS ASPHALT MIXTURE TO PERFORMANCE RELATED CRITERIA**

by

**Fazleen Hanim AHMAD KAMAR & Jazlina Nor SARIF**

*Public Works Department, Malaysia  
fazleen@jkr.gov.my, jazlina@jkr.gov.my*

## **ABSTRACT**

Raveling is the most common mode of failure of porous asphalt surfacing. This could be attributed to the large and interconnected air voids which accelerate aging of the binder. When the thin film of binder reacts with oxygen from the air which readily occupy the large air voids, it becomes harden rapidly. Exacerbated by the movement of water through the air voids when it rains, these could be the major contributor to the disintegration of aggregate particles from the road surfacing.

This paper highlights the performance of various types of porous asphalt in Malaysia since it was first introduced in 1991, review the appropriate laboratory testing at the mix design stage which would ensure satisfactory performance of porous asphalt during in-service, recommends an appropriate design procedure for porous asphalt mixture that will render satisfactory performance of the asphalt as a road surfacing material and describes the development of standard specification for porous asphalt for use in Malaysia.

## **1.0 INTRODUCTION**

Porous asphalt is a hot bituminous mixture normally used as a special-purpose wearing course. It is produced using open-graded aggregates mixed with essentially polymer modified binder. Due to the open-graded nature of the aggregates, it contains a relatively high and interconnected air voids after compaction which are permeable to water. As this non-structural bituminous layer is designed in such a way that any surface water entering into it is rapidly drained to the road shoulders, it is laid on a structurally sound and impermeable pavement surface with adequate cross fall.

Raveling, or loss of aggregate particles from the road surfacing, is reportedly being the most dominant mode of failure in the Netherlands, the most widely quoted problems in the United States and is visually prominent in Malaysia after several years of trafficking. This could be attributed to the large and interconnected air voids which accelerate aging of the binder. When the thin film of binder which coats the aggregate particles reacts with oxygen from the air which readily occupy the large air voids, the binder becomes harden rapidly. Exacerbated by the movement of water through the air voids when it rains, these could be the major contributor to the disintegration of aggregate particles. This mode of surfacing failure may also be due to stripping of the binder from the aggregate particles due to moisture susceptibility.

## 2.0 DEVELOPMENT OF POROUS ASPHALT

Porous asphalt evolved in the United States from experimentation with a seal coat treatment in the 1950s. Owing to its nature of application whereby aggregates are spread and rolled lightly into a layer of bitumen, thus provides improved friction, it is relatively short-lived by loss of aggregates, under high speed and heavy traffic. In an effort to retain the benefits of a surface treatment that enhances friction, and to reduce aggregate loss, this seal coat treatment was later improved by mixing chip seal type aggregates with relatively high bitumen content in a hot-mix plant facility and laying the mix with a conventional paver. This resulted in a surfacing of an open surface texture and enhanced friction.

Porous asphalt was developed in Europe as a special-purpose wearing course that drains water from the pavement surface and reduces rolling tyre noise levels. Even though the improvement of friction between the pavement surface and vehicle tyres is known to be an advantage of this wearing course, the porosity of the mixture is the dominant feature in Europe. Minimum in-place air voids are, therefore, more strongly promoted in Europe than in the United States.

In Germany, special-purpose surface courses called Dränasphalt (drainage course) or Lärmindernde Deckschicht (noise-abating wearing course) were developed in 1971.

At about the same time, the Netherlands Study Center for Road Construction was asked to research characteristics of road surfaces and, particularly, to find ways to improve their safety during periods of rain. Therefore, porous asphalt was initially used on grounds of traffic safety. Since 1990, however, porous asphalt was used to reduce traffic noise in tandem with European and national legislations on noise. An official policy has been issued that by the year 2010, all its main roads would be surfaced with porous asphalt. Some details on the porous asphalt mixture which is being used throughout the Netherlands is described below [1].

### 2.1 Porous Asphalt in the Netherlands

#### 2.1.1 Mix Design

When it was first applied, mix design in the Netherlands was empirical in nature and based on field observations. Currently, the following formulation is adopted for single layer porous asphalt after extensive field trials;

**Constituent materials:** Are made up of aggregates from crushed stones 6 to 16 mm and crushed sand 0.063 to 2 mm, hydrated lime filler 4.5% of aggregates or 25% of binder, and penetration grade 70 -100 bitumen without polymer additives or fibers at 4.5% of aggregates.

**Mix design procedure:** Four Marshall specimens are prepared by mixing specified aggregate gradation with 4.5% bitumen and compacted by applying 50 blows per face. Void content is determined from specimen geometry. The required minimum void content is 20%. No mechanical tests are carried out on the specimens.

**Construction:** Variation in bitumen content is tolerated at +/- 0.5% and void content can vary between 15% to 25%. Percentage compaction in relation to laboratory density at 50 blows per face is 97%. No roller vibration and pneumatic tyre roller. Laying thickness 50 mm, laying temperature 130 – 170 °C.

Porous asphalt in the Netherlands exhibits an average service life of 12 and 16 years on the slow lanes and fast lanes respectively.

#### 2.1.2 Porous Asphalt

The first application of porous asphalt in Malaysia was in 1991 when the Public Works Department of Malaysia (JKR) undertook a project to resurface Federal Route 1 between Cheras and Beranang using the Skid Resistant Silent Surfacing (SRSS), an open-graded asphalt mixture with aggregate gradation of nominal size 14 mm and binder content 5.5% [2]. The binder was modified with an ethylene methacrylate (EMA) polymer, Polybilt XCS 503. Prior to the placement of the asphalt, a special

tack coat called Neomed which is a diphasic cationic elastomeric bitumen emulsion consisting approximately 36% water, 62% bitumen and 2% natural rubber latex was used.

During the production and construction of the SRSS, it was recorded that the mixing temperature was about 190°C, the laying temperature between 140 to 170°C and the rolling temperature between 120 to 140°C. The compaction was accomplished with a combination of two passes using a 6-ton steel wheel roller and two passes of an 8-ton steel wheel roller.

Air voids in cored samples indicated that the minimum requirement of 20% was complied with. The skid resistance values were however quite low with an average of 40. This was probably due to relatively thick binder film coating the aggregates. The average texture depth was 0.70 mm, which was two times that of the conventional asphaltic concrete surfacing of 0.36 mm.

Although no quantitative measurements were carried out, it was observed that SRSS surfacing did reduce vehicle spray, headlight glare and surface ponding of water during downpour.

After about three years, it was generally observed that the drainability of SRSS surfacing had diminished. Since there was no rutting recorded after this time, this failure could be due to the clogging of the air voids by dust and debris from passing vehicles.

Another type of porous asphalt using bitumen modified with a styrene butadiene styrene (SBS) polymer called Europrene Sol-T was constructed on the Federal Highway in 1995.

After approximately one year of trafficking, the mean texture depth of the road surfacing was found to decrease from 1.0 mm to 0.75 mm. No rutting was recorded after a similar period despite being laid on a heavily trafficked highway. Field measurements of water drainability had indicated that there was a sign a gradual clogging of the air voids. Drainability of 300 ml/s immediately after construction had been reduced to 120 ml/s.

Subsequently, several other types of porous asphalt were laid at various locations such as follows;

- i. Porous asphalt with Gilsonite on Route 1, Seremban – Mantin, 1995.
- ii. Porous asphalt with Cariphalte on Jalan Kangkar – Teberau, Johor Bahru, 1997.
- iii. Porous asphalt with Cariphalte on Federal Highway (resurfacing the old porous asphalt that was constructed in 1995), 2002.
- iv. Porous asphalt with crumb rubber on Route 2, Kuantan, 2003.

### **3.0 ADVANTAGES AND DISADVANTAGES OF POROUS ASPHALT**

#### **3.1 Advantages**

Owing to its high air voids and rough surface texture, porous asphalt surfacing offers a number of advantages as described below.

##### **3.1.1 Improve in Skid Resistance**

With greater texture depth and the absence of surface water on the road surfacing, vehicle tyres experience maximum road holding. During the wet weather, the surface water is readily drained away or pressed down with the surfacing as the tyres pass. This phenomenon reduces the tendency for the vehicle to skid especially during braking at high speeds.

##### **3.1.2 Reduction of Aquaplaning**

The presence of surface water on normal dense asphalt surfacing gives rise to aquaplaning whereby the vehicle tyres are not in full contact with the road surface particularly when the vehicle is traveling at high speeds. High air voids in the porous asphalt layer swiftly drain surface water into it, thus reducing aquaplaning.

### 3.1.3 Reduction in Splash and Spray

On a normal dense asphalt surfacing, water is trapped on the road surface when it rains which results in splash and spray as vehicles traverse. This phenomenon restricts visibility to the driver. Porous asphalt surfacing absorbs surface water like a sponge. A 40 mm thick layer of porous asphalt can absorb up to 8 mm of rainfall before it becomes saturated.

### 3.1.4 Reduction in Headlight Reflection and Glare

Due to the open texture of the road surfacing and the absence of surface water, reflection and glare from vehicles headlights are reduced, thus improved visibility of painted pavement markings on wet road surfaces at night. Reduction in glare also in general helps to improve driver visibility at night.

### 3.1.5 Reduction of Rolling Tyre Noise Levels

In comparison with dense graded asphalt mixtures, a reduction of traffic noise at source by an average of 3 dB(A) can be achieved by porous asphalt. This is equivalent to doubling the distance between the noise source and the receiver, or reducing the traffic volume by 50%, or reducing traffic speed by 25%. The degree of acoustic absorption is a function of the air voids and of the maximum aggregate size of the porous asphalt; high air voids absorb noise more efficiently while smaller aggregate sizes tend to produce less noise.

### 3.1.6 Increase Resistance to Rutting

The potential of rutting of porous asphalt mixture was evaluated by Kandhal et al with the Asphalt Pavement Analyser [3]. Cylindrical specimens were tested at 64°C for 8000 cycles and rut depth measured. Rut tests were conducted on four specimens with varying percentage passing 4.75 mm sieve at design binder contents. The Asphalt Pavement Analyser was used to rut the mixes under a wheel load of 445 N and a hose pressure of 690 kPa. The mixes were tested at 64°C since the PG grade of the binder used was PG 64-22. Table 1 shows the test results. The rut depths at 8000 cycles do not show any particular trend with percent passing the 4.75 mm sieve. All the rut depths are very small, less than 5 mm, and are considered acceptable. The high resistance to rutting is attributed primarily to the aggregate skeleton structure with stone-on-stone contact arrangement.

**Table 1.** Variation of rut resistance with gradation.

Gradation (% passing 4.75 mm sieve)	Rut Depth at 8000 cycles, mm
15	4.05
25	3.83
30	4.29
40	3.41

### 3.1.7 Increase Resistance to Cracking

Due to its high air voids, the occurrence of cracks in the road surfacing is not anticipated as the emergence of stresses and strains that would initiate cracking would readily dissipate in the air voids.

## 3.2 Disadvantages

### 3.2.1 Raveling

The service life of porous asphalt is normally considered in terms of raveling, the most common mode of failure. Raveling is normally due to hardening of the binder facilitated by the movement of air and water through the air voids. It can also be caused by stripping of binder from aggregate due to moisture susceptibility.

Raveling is invariably expedited by thin binder film coating the aggregates. A relatively soft bitumen that hardens slowly and thick film of bitumen coating the aggregates are essential to durability of the mixture. Mallick et al reported that raveling in open graded friction course in the US is due to inadequate bitumen film thickness, excessive aging of binder and loss of bitumen-aggregate adhesion [4]. The use of appropriate binder modifiers to improve temperature susceptibility and resistance to oxidation, and increasing binder film thickness by using high viscosity modified binders or incorporating cellulose fibres or the use of hydrated lime filler help to prolong the service life of porous asphalt.

### **3.2.2 Clogging**

The other prime factor affecting the performance of porous asphalt is permeability loss due to clogging. Together with raveling, these factors could be affected by the maximum size of aggregates, gradation of aggregates, type of binder and quantity of binder coating the aggregates. It has been shown that In general, higher coarse aggregate content implicates higher porosity and permeability but a reduction in strength and lacking in durability.

Clogging of voids is quite severe on the road shoulders but not a problem on the traffic lanes as porous asphalt is generally laid on high speed roads. Clogging is mitigated by cleansing the porous asphalt surfacing once or twice a year using a specially built hydro-vacuum machine.

Experience in some countries such as USA indicates that significant loss in permeability of porous pavement was experienced after two to three years because of clogging of voids by deicing materials or other debris [4]. In Singapore, local residual soils deposited from dirty wheels and vehicles carrying earth has been a major source of materials contributing to clogging of porous asphalt layers. [5]

### **3.2.3 Bitu-planing**

Bitu-planing phenomenon is attributed to the texture of the porous asphalt surfacing itself which comprises of protruding coarse aggregate. This gives rise to higher contact pressure at the vehicle tyre – road surface interface. When emergency brakes are applied, the tyre slips on the surface generating enough heat due to melt the bitumen. The melted bitumen forms a slippery surface that facilitates skidding. This problem is usually mitigated by imposing speed limit on newly laid porous asphalt.

## **4.0 RECOMMENDED DESIGN PROCEDURE FOR POROUS ASPHALT**

### **4.1 Step 1: Selection of Aggregates**

In general, the surface area of porous asphalt mixture is less than half of conventional asphaltic concrete mixture. The contacts between aggregate are fewer in porous asphalt mixture and therefore the stress at the contact points is higher. It is thus imperative to have hard and crushed aggregate which are reasonably cubical rather than flaky or elongated. If aggregates are too weak, fragmentation will occur especially during laying and compacting the mixture. This is undesirable as it would change the mix gradation and reduce the air voids.

Aggregate for porous asphalt mixture shall be a mixture of coarse and fine aggregates, and mineral filler. Superpave defines coarse aggregate as those particles which are retained on 4.75 mm sieve, fine aggregate as those passing 4.75 mm sieve and mineral filler as those passing 75 µm sieve [6].

#### **4.1.1 Coarse Aggregate**

As hard and crushed aggregate are essential to ensure satisfactory performance of porous asphalt surfacing, it is therefore recommended that coarse aggregate shall be only screened crushed hard rock (steel slags are also allowed by DOT, UK [8] whereas only crushed granite stone is specified in Singapore [9]), angular in shape and free from dust, clay, vegetative and other organic matter, and other deleterious substances [7][8].

ASTM D 7064 specifies that coarse aggregate should have abrasion values of less than 30% when tested in accordance with ASTM C 131 whereas NAPA recommends maximum loss of 25% [7] [10].

The loss by abrasion and impact in the Los Angeles machine when tested in accordance with ASTM C 131 shall be not more than 25% [7]. In Singapore, the maximum loss allowed for in a similar test is 20% [9].

The aggregate crushing value when tested in accordance with BS 812 shall be not more than 25% [9]. Aggregate impact value shall be not more than 25% [9]. Ten percent fines value shall be not less than 180 kN (dry) [8].

Resistant to polishing is also essential for the aggregate as the porous asphalt is mostly used as a wearing course. Therefore, the requirement for polished stone value is in general relatively high. For example, specifications based on the British polishing wheel require polished stone values at least 0.45 for heavy volumes of traffic, and at least 0.40 for all other traffic volumes [7]. The requirement in Belgium and Switzerland is 50 minimum. However, requirements in some other countries are not as high, either for practical reasons whereby hard or very hard aggregate are not available or because it is felt that macrotexture of the surfacing overrides the microtexture of the coarse aggregates. For example, the requirement in Spain and Italy is 40 and 44 minimum respectively [11].

As for cubical aggregate requirement, The Department of Transport UK specifies that the flakiness index when tested in accordance with BS 812 shall be not more than 25% [8]. NAPA recommends that the aggregate portion which is retained on the 9.5 mm sieve when tested in accordance with ASTM D 4791 shall contain not more than 15% by weight of flat and elongated particles [7]. Flat and elongated particles (ASTM D 4791) 3:1 20% max, 5:1 5% max [12].

ASTM D 7064 specifies that the percentage of flat and elongated particles should not exceed 10% with a ratio of 5:1 in maximum to minimum dimension in accordance to ASTM D 4791 [10].

### **5.1.2 Fine Aggregate**

For similar reasons as stated above, it is recommended that fine aggregate shall be only screened crushed aggregate or quarry fines. They shall be non-plastic and free from clay, loam, aggregations of material, vegetative and other organic matter, and other deleterious substances. They shall conform to the following physical and mechanical quality requirements;

- i. The weighted average loss of weight in the magnesium sulfate soundness test (five cycles) when tested in accordance with AASHTO T 104 shall be not more than 20%.
- ii. The water absorption when tested in accordance with MS 30 shall be not more than 2%.

ASTM D 7064 specifies that the fine aggregate should have an uncompacted voids content of at least 40% when tested in accordance to ASTM C 1252 [10]. This property is normally referred to as the fine aggregate angularity. This property ensures a high degree of fine aggregate internal friction and resistance to rutting. It is defined as the percent air voids present in loosely compacted aggregates smaller than 2.36 mm. The standard test is ASTM C 1252 "Uncompacted Void Content of Fine Aggregate as influenced by Particle Shape, Surface Texture and Grading". The test determines the loose uncompacted void content of a sample of fine aggregate. When measured on any aggregate of a known grading, void content provides an indication of that aggregate's angularity, sphericity and surface texture.

ASTM D 7064 also specifies that the fine aggregate should have sand equivalent value of at least 45% when tested in accordance to ASTM D 2419 [10]. It determines the clay content which is the percentage of clay material contained in the aggregate fraction that is finer than 4.75mm. It is measured by ASTM D 2419 "Sand Equivalent Value of Fine Aggregate". The test indicates the relative proportion of clay or plastic fines in fine aggregate that pass 4.75 mm sieve. The 'sand equivalent' expresses the concept that most fine aggregate are mixtures of desirable coarse particles and undesirable clay or plastic fines. Clay and excessive amounts of plastic fines in aggregate are detrimental to mix performance.

Clough and Martinez conducted an extensive laboratory investigation and showed a very good correlation between the sand equivalent value of aggregate and resistance to stripping of bituminous mixtures [13].

Aschenbrener studied several bituminous mixtures in Colorado and concluded that sand equivalent value provides a reasonable indication of mix susceptibility to moisture-induced damage [14].

### **4.1.3 Mineral Filler**

Traditional filler in the form of ordinary Portland cement is very rarely used in countries which developed sound concepts in asphalt technology. It is hereby recommended that limestone dust or hydrated lime shall be used as filler. The material shall pass 75  $\mu\text{m}$  sieve by not less than 70% by weight. The amount of filler to be added shall be not less than 2% by weight of the combined aggregates when limestone dust is used and shall be not more than 2% if hydrated lime is used. If necessary, the use of 2% hydrated lime in combination with a small quantity of limestone dust is permitted.

With lime as mineral filler, other benefits in the form of increased resistance to stripping of aggregate and oxidation of bitumen could also be gained.

#### **4.1.3.1 Lime as anti-stripping agent**

The anti-stripping mechanism of lime could be described as follow;

- a. Acids in the bitumen migrate to the bitumen – aggregate interface and form salts with sodium or potassium minerals which are frequently associated with stripping-prone aggregate. These salts are much more soluble in water than calcium salts. Lime encourages the formation of calcium salts resulting in a material which is more resistant to stripping [15][16].
- b. Lime reacts with most silicate aggregate to form a calcium silicate crust which has a strong bond to the aggregate and has sufficient porosity to allow penetration of bitumen to form another strong bond [15][16]. [

As an anti-stripping agent, hydrated lime  $\text{Ca}(\text{OH})_2$  and quick lime are effective. Dolomitic lime (both Type S and N) is similarly effective but calcium carbonate  $\text{CaCO}_3$  lime is not as effective [16].

In the Kuala Lumpur International Airport (KLIA) project, lime in the form of calcium carbonate  $\text{CaCO}_3$  powder was entirely used as filler cum anti-stripping agent in the construction of the binder course and wearing course of the runways and taxiways.

#### **4.1.3.2 Lime as anti-oxidant**

Lime could also act as anti-oxidant – reducing the rate of oxidation and hence hardening of bitumen possibly by absorption of polar oxidation products on the lime surface which could act as pro-oxidant [17].

### **4.2 Step 2: Selection of Bituminous Binder**

When porous asphalt was promoted in the US in the 1970s, polymer modified binders were not available at that time, and neither fibers were used. As such, design bitumen contents were kept relatively low because of binder draindown problems during transportation. PIARC Technical Committee on Flexible Roads reported that virtually all countries using porous asphalt mixtures carried out their preliminary works with conventional bitumen, with the Netherlands continue to use this binder until nowadays. In Belgium, conventional bitumen (80-100) is used only for low traffic roads. In France, conventional 60-70 and 80-100 bitumen are referred to. In Spain, 20% of porous asphalt mixtures have 60-70 and 80-100 bitumen. In Switzerland, a draft standard requires polymer modified bitumen or bitumen with additives like fibers. In the United Kingdom, the 1988 BS 4987 recommends 80-100 bitumen. The requirement in Italy is for modified bitumen.

Because of the large and interconnected air voids, porous asphalt tends to age more rapidly. Thick films of bituminous binder with improved resistance to age hardening are essential. It is therefore recommended that the bituminous binder for use with porous asphalt shall be polymer modified bitumen of performance grade PG76 or higher in compliance with AASHTO Standard M320-02.

Based on many years of experience with porous asphalt in Europe, it has been shown that the use of polymer modified binders with improved resistance to age hardening enhance the durability of the surfacing material.

The polymer modified bitumen shall be produced by incorporating an appropriate quantity of synthetic polymer additive to conventional bitumen. The properties of the polymer modified bitumen shall be as shown in Table 2.

### 5.3 Step 3: Selection of Design Aggregate Gradation

The following mix design procedure is recommended by NCAT for the new-generation porous asphalt mixture based on the laboratory study at NCAT, observation of in-place performance of porous asphalt mixtures in Georgia, and experiences in Europe [4]. The aggregate gradation envelope is shown in Table 3.

**Table 2.** Properties of polymer modified binder.

Tests	Requirement	Test Specification
<b>Original Binder</b>		
Viscosity, max. 3 Pa.s, test temperature °C.	135	ASTM D 4402
Dynamic shear, $G^*/\sin \delta$ min. 1.00 kPa, 10 rad/s, test temperature °C.	76	AASHTO T 315
Penetration, 100 g, 5 s, 25 °C, 0.1 mm.	Report	ASTM D 5
Ring and Ball softening point, minimum, °C.	60	ASTM D 36
Rolling Thin Film Oven (AASHTO T 240 or ASTM D 2872) Residue		
Mass loss, max %.	1.00	AASHTO T 240 or ASTM D 2872
Dynamic shear, $G^*/\sin \delta$ min. 2.20 kPa, 10 rad/s, test temperature °C.	76	AASHTO T 315

**Table 3.** Aggregate gradation envelope.

Sieve Size, mm	Percentage Passing, by weight
20.0	100
14.0	85 - 100
10.0	55 - 75
5.0	10 - 25
2.36	5 - 10
0.075	2 - 4

A gradation with no more than about 20% passing the 4.75 mm sieve is required to achieve stone-on-stone contact condition and provide adequate drainability in porous asphalt mixes. This recommended aggregate gradation band is slightly different from those that have been previously used in Malaysia such as on the Route 1 Cheras – Kajang and Federal Highway as shown below.

**Table 4.** Aggregate gradation previously used in Malaysia.

Sieve Size, mm	Percent Passing, by weight	
	SRSS (typical curve) Route 1, Cheras –Kajang 1992	Porous Asphalt Federal Highway 1995
19.0	-	100
12.5	100	30 - 90
9.5	87	25 - 55
6.3	35	15 - 40
2.36	13	8 - 20
0.425	4	3 - 12
0.075	1.4	2 - 6

In porous asphalt, the quantity and gradation of coarse aggregate determines porosity, hence permeability. In general, porosity can be increased by increasing the proportion of the coarse mineral aggregate and reducing the amount of fine aggregate fraction. Abdullah et al concluded that increasing void in the mineral aggregates and air voids in the mix by choosing the coarse aggregate gradation for the asphalt mix makes it more porous and water permeable [18].

Design aggregate gradation shall be selected from the recommended aggregate gradation limit as given in Table 3. Selection of the design gradation should entail blending selected aggregate



stockpiles to produce three trial blends. It is suggested that three gradations along the coarse and fine limits, and along the middle of the limits shall be tried.

For each trial gradation, determine the dry-rodded voids in coarse aggregate of the coarse aggregate fraction ( $VCA_{DRC}$ ). Coarse aggregate is defined as the aggregate fraction retained on the 4.75 mm sieve.

Porous asphalt should have a coarse aggregate skeleton with stone-on-stone contact to minimize rutting. The condition of stone-on-stone contact within porous asphalt mixture is defined as the point at which the voids in coarse aggregate (VCA) of the compacted mixture is less than the VCA of the coarse aggregate fraction only ( $VCA_{DRC}$ ) in the dry rodded test (AASHTO T19).

#### 4.4 Step 4: Determination of Design Binder Content

With high air voids and open-graded aggregates, high binder contents are essential to ensure mix integrity, increase resistance to oxidation and raveling, and improve durability. The quantity of binder shall be carefully balanced such that it is not deemed too excessive to cause binder drain-down during production, transport and laying, and neither it is deemed too little to adversely affect durability.

Using the selected design gradation, prepare porous asphalt mixtures at three binder contents in increments of 0.5%. Conduct binder draindown test on loose mix at a temperature 15°C higher than anticipated production temperature. Compact mixtures using 50 blows Marshall compactor and determine air void contents. Conduct the Cantabro abrasion test on unaged and aged (7 days @ 60°C) specimens.

The binder content that meets the following criteria is selected as design binder content;

- i. Air voids. The air void content should not be less than 18%.
- ii. Abrasion loss of unaged specimens. The abrasion loss from the Cantabro test should not exceed 20%.
- iii. Abrasion loss of aged specimens. The abrasion loss from the Cantabro test should not exceed 30%.
- iv. Binder draindown. The binder draindown should not exceed 0.3%.

##### 4.4.1 Laboratory Compacted Specimen

Porous asphalt mixes shall be compacted in the laboratory by using the Marshall method, in accordance with ASTM D 1559. The specimens shall then be used for further analysis as described hereof.

Because of the limited compactive effort applied in the field on porous asphalt mixes to achieve high air voids, the number of blows per side shall be 50.

##### 4.4.2 Air Voids Requirement

The design and in-place air voids shall be in the range of 18 to 25 percent. Below are some typical laboratory compaction and air voids requirements adopted in a number of countries [19];

**Table 5.** Design air voids in various countries.

Country	Laboratory Compaction Method	Design Air Voids, %
Australia	50 blow Marshall or 80 gyratory cycles	15 – 20, or 18 – 23
New Zealand	75 blow Marshall	18 – 25
South Africa - High traffic - Low to medium traffic	50 blow Marshall	22 min 18 – 22
U.S. (typical)	50 blow Marshall	17 – 22
Europe (typical) - Austria, Belgium, Germany, Netherlands, Spain	50 blow Marshall	20 – 24

France	40 gyratory cycles	20 – 28
Singapore [9]	50 blow Marshall	26 max

The recommended air voids of 18 – 25% would normally provide adequate drainability of the porous asphalt road surfacing to allow satisfactory drainage of rain water during heavy rainfall. There are various standard requirement and test method for the surface drainability, some of which are described as follows;

- i. NAPA IS 115 refers to the permeameter as described in TRR 1265 [7]. Permeability of porous asphalt surfacing is expressed by the time it takes a specified quantity of water (normally 2.3 litres) to flow from a cylinder having an interim diameter of 190 mm through the porous asphalt surfacing. Outflow times of 20 to 40 seconds are expected for newly placed porous asphalt.
- ii. NCAT Report No. 2000-01 mentioned about the Florida Department of Transport falling head laboratory permeability test [4]. The coefficient of permeability obtained with different gradation varied from about 20 m/day to 120 m/day.
- iii. The coefficient of permeability of Georgia open graded friction course measured using the falling head permeameter has been recorded to be about 240 feet/day. The porous European mixes could achieve 340 feet/day.
- iv. The Department of Transport, United Kingdom specifies the relative hydraulic conductivity of porous asphalt surfacing to be not less than  $0.12 \text{ s}^{-1}$  for the mean of five consecutive determinations at 20 meter spacing [8]. Individual determinations shall be not less than  $0.06 \text{ s}^{-1}$ . The relative hydraulic conductivity is the reciprocal of the outflow time minus the series resistance time. The outflow time is defined as the time that elapses for an outflow of 2.0 litres through the permeameter while the series resistance time is the outflow time when the outlet is not restricted by a surfacing. It shall be subtracted from measurements of outflow time when the permeameter is used on a surfacing.
- v. JKR recommended drainability of at least 1 litre of water a minute over a discharge area of  $54 \text{ cm}^2$  [22]. The drainability of the porous asphalt surfacing on the Federal Highway had been measured to be about 18 litres/minute through a discharge area of  $54 \text{ cm}^2$  immediately after construction.

#### 4.4.3 Binder Draindown Test

In a bituminous mixture, the bitumen functions to coat the aggregate and this is possible when the bitumen is at the appropriate viscosity hence temperature. At a given binder temperature, hence viscosity, there is a maximum bitumen film thickness coating the aggregate beyond which the excess binder will be drained. The higher the temperature, the lower is the viscosity and hence the thinner the binder film. Consequently, higher temperature implicates more draindown. The phenomenon of binder draindown can be explained in this context and is experienced by mixes having aggregate of small surface area such as porous asphalt, stone mastic asphalt and open-textured bituminous macadam. When it does take place, usually during storage and transportation, it will cause deficient binder in part of the mixture which may lead to raveling, and excessive binder in other part of the mixture which may result in bleeding and loss of permeability.

Kandhal et al have shown that the amount of binder draindown is dependent on percentage passing 4.75 mm sieve (ie. the gradation), grade of binder and test temperature (refer to Table 6) [3].

**Table 6.** Variation of binder draindown with gradation, grade of binder and test temperature.

Gradation (% passing 4.75 mm sieve)	Test Temperature, °C			
	160		175	
	PG 64	PG 76	PG 64	PG 76

15	0.45	0.05	1.27	0.30
25	0.10		0.25	
30	0.11		0.24	
40	0.12		0.19	

The maximum permissible binder draindown is usually set at 0.3%. There are many versions of doing this test, some of which are described as follows;

- i. NAPA IS 115 recommended the level of acceptability in the binder drain-down test is a maximum of 0.3% binder drainage by weight of the mixture following heating at 175 °C for two hours in an oven [7].
- ii. NCAT method is based on NCHRP Report 425 1999. A sample of loose mixture, placed in a wire basket having ¼ in. mesh openings, is kept in a forced draft oven for one hour at 160°C and 175°C ie. 25°F above normal production temperature (NCAT Report No. 2000-01 recommended test be conducted at the proposed mixing temperature) [4]. The maximum permissible drain-down is 0.3%.
- iii. The Schellenberg drain-down test used in Europe is conducted at 170°C for 60 minutes on 1 kg specimen. Losses greater than 0.3% indicate that segregation may be a problem [20].
- iv. The Department of Transport, United Kingdom specifies drainage basket be made from perforated metal with 3.1 +/- 0.1 mm diameter holes and with 38 +/- 3 % open area, on sides and base to form 100 +/- 2 mm cubes [8]. Test temperature with 100 pen bitumen plus 5% natural rubber is 160 +/- 3°C, heating period is 3 – 3.25 hours. The drain-down test is used to determine the target binder content. Initially, the mixed binder content is determined where the binder drainage is 0.3%. The target binder content is the mixed binder content minus 0.3%.
- v. NAPA QIP 122 defines drain-down to be that portion of binder which separates itself from the sample as a whole and is deposited outside the cylindrical-shape wire basket during the test. [21] The basket shall be manufactured using standard 6.3 mm sieve cloth, diameter and height of cylinder 108 mm and 140 mm respectively. Any noticeable aggregate particles that are deposited outside the basket should be added back into the sample and not counted as drain-down. The sample in the basket, either prepared in the laboratory or obtained from field production, is placed in a forced air oven for 1 hour +/- 1 minute at anticipated plant production or mixing temperatures.
- vi. JKR recommended that 12 kg of loose mix be stored in an oven for 6 hours at 160°C in a suitable container with steel mesh bottom. Binder drain-down shall be not more than 0.2% [22].

In the final draft specification for porous asphalt prepared by JKR, binder draindown test is specified to be carried out in accordance with the National Asphalt Pavement Association QIP 122 procedure [21]. A sample of porous asphalt shall be placed in an oven for 1 hour at an anticipated mix production temperature in a wire basket fabricated using standard 6.3 mm sieve cloth. Any binder drain down from the asphalt shall be collected in a pan. The binder drain-down shall be not more than 0.3% by weight of the total mix.

#### 4.4.4 Cantabro Test

Resistance to raveling or aggregate loss of porous asphalt mixture in Europe is evaluated in a laboratory test called the Cantabro Test. This test was developed in the early 1980s in the Road Laboratory of the University of Cantabria, Spain. There are many versions of doing this test, some of which are described as follows;

- i. NAPA IS 115 stipulates that three Marshall specimens shall be placed in the Los Angeles machine with the steel balls removed [7]. The weight loss of the specimens is determined after 300 revolutions at a temperature of 25°C. It shall not exceed 30%.
- ii. PIARC Technical Committee recommended that Marshall specimens be subjected, one by one, to 300 rotations in the Los Angeles drum, without traditional steel spheres, at a well

- defined temperature (18°C or 25°C) [11]. The abrasion, expressed as a loss of mass, is charted according to the binder content. The loss through wear decreases when the binder content increases, the curve slopes downward and becomes flatter when a certain percentage of bitumen is reached, which appears to correspond to the minimum needed to ensure adequate cohesion. It is accepted that the mass loss must be less than 30% for a test temperature of 18%, and 25% (sometimes even 20%) for a test temperature of 25°C.
- iii. NCAT Report No. 2000-01 describes that Marshall specimen, compacted with 50 blows on each side, is placed in the Los Angeles rattler without the charge steel balls. The operating temperature is usually 25°C. The machine is operated for 300 revolutions at a speed of 30 to 33 rpm. The recommended maximum permitted abrasion loss value for freshly compacted specimens is 20% [4].
  - iv. Perez-Jimenez and Gordillo reported that one of the Spanish design criteria is the loss of mass in the Cantabro test (50 blows per face, 300 revolutions, without balls) shall be not more than 35% and, generally, not more than 30%, if the test is carried out at 18°C [23]. The other criterion is the voids in the mix shall be more than 18% and, preferably, not less than 20%.
  - v. Because of very high air voids, the binder in open-graded mix is prone to hardening at a relatively fast rate which may result in reduction of cohesive and adhesive strength leading to raveling. Therefore, it is recommended that mix design be subjected to an accelerated aging test. Accelerated aging in laboratory is accomplished by placing five Marshall specimens compacted with 50 blows in a forced draft oven set at 60°C or 168 hours (7 days). The specimens are then cooled to 25°C and stored for 4 hours prior to Cantabro test. The average of the abrasion losses obtained on five aged specimens shall be not more than 30% while individual result shall be not more than 50% [4][10].
  - vi. And because of very high air voids too, the mix is prone to stripping by the action of water, hence the need for good adhesion between the binder and aggregate in the presence of water. In the Spanish mix design method, resistance to stripping is evaluated in the Cantabro test by determining the loss of mass of specimens that were submerged in water at 49°C for 4 days [23]. However, no permissible limit is given. Typical percentage losses obtained were 24% and 32% at 5.5% and 4.5% binder content respectively.
  - vii. JKR recommended five Marshall specimens compacted with 50 blows be kept at 25 °C for at least 6 hours before each of them is subjected to abrasion in the Los Angeles drum, rotated at 188 to 208 rad/s for 300 revolutions without abrasion loads [22]. The average loss of mass shall be not more than 15%.

Meor et al has found out that an improvement in resistance to disintegration is noticeable by decreasing the maximum aggregate size [24]. The resistance to disintegration can increase by up to 155% when porous asphalt is made with maximum aggregate size 10 mm compared to maximum aggregate size 20 mm. The coarser blend has lower aggregate surface area, lower design binder content and hence lower aggregate inter particle adhesion. This probably explains the cause for its lower abrasion resistance.

## 5.0 CONCLUSION

Porous asphalt is more likely to experience surface distresses in the form of raveling and clogging rather than cracking and rutting. Stresses which lead to cracking are expected to be relieved into the air voids of the porous asphalt. Non-structural rutting is unlikely as the interlocking of aggregates in the porous asphalt reduces plastic deformation by traffic. Rutting will be more likely to be attributed to underlying layers.

The service life of porous asphalt is normally considered in terms of raveling, the most common mode of failure. Raveling is normally caused by binder hardening which is facilitated by the movement of air and water through the high and interconnected air voids within the asphalt mixture. It could be exacerbated by stripping of binder from aggregate due to moisture susceptibility. As such, it is imperative to design the asphalt mixture that is able to resist loss of aggregate particles from the road surfacing by traffic.

The two primary tests which are commonly incorporated into the design procedure of porous asphalt mixture worldwide are binder draindown and Cantabro. Both tests play significant part in ensuring satisfactory resistance to raveling of the asphalt mixture. By limiting binder draindown of specimen in the laboratory when heated and stored at anticipated mixture production temperature for one hour, it minimises the occurrence of deficient binder in part of the mixture which may lead to raveling. On the other hand, by limiting the loss of mass of specimen by abrasion and impact in the Los Angeles drum in the Cantabro test, it minimises the disintegration of aggregate particles from the road surfacing by having adequate bitumen film thickness and bitumen – aggregate adhesion. This assessment could be further improved by using specimen subjected to accelerated aging.

*Note: Based on past experience and literature review, standard specification for porous asphalt for use in Malaysia has been finalised and circulated in January 2008.*

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